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Evaluating the impact of an agricultural land-use change adaptation strategy on household crop production in semi-arid Ghana

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In this study, the Land Use Dynamic Simulator model was applied to investigate the impact of farm credit as an adaptation strategy to cope with effects of climate variability on agricultural land-use change and crop production in the Vea watershed in Ghana. The authors identified the determinants of crop choices within the landscape (e.g., farm household and biophysical characteristics of farm plot). The crop choice sub-model was then linked to the crop yield sub-model to determine the yields of selected crops. In adapting to the impacts of climate variability, the maize credit adoption sub-model under the maize cultivation credit scenario was integrated into decision-making. This was simulated for a 20-year period, and compared with the business-as-usual scenario. Under the simulated maize credit scenario, maize adopters increased from about 20 per cent to about 50 per cent and the area allocated for maize cultivation significantly increased by about 266 per cent. Consequently, the average annual aggregated household crop yield increased by 6.3 per cent higher than in the business-as-usual scenario. This simulation study shows that access to maize credit can significantly influence agricultural land-use change and food availability in the study area. However, although access to farm credit may translate into food availability, the sustainability of this strategy is questionable.

Keywords: Agricultural production, climate change, adaptation, dry lands, farm credit, food availability, multi-agent simulation

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Introduction

The impacts of climate change on agricultural productivity are expected to be severe for Africa, where nearly 50 per cent of the population relies on agriculture (NEPAD, 2013) with an increasing likelihood of diminished yield potential of major crops (Sultan *et al.*, 2013). The Sahel and tropical West Africa are particularly vulnerable to the effects of climate change (Diffenbaugh & Giorgi, 2012). One of the countries of this region, Ghana, where most farmers rely on rain-fed agriculture, exemplifies this problem, especially in the northern regions of the country.

Adaptation to variable rainfall patterns in the region is crucial because without it, the livelihoods of smallholder farmers are threatened (Amikuzuno & Donkoh, 2012).

To cope with the highly variable climatic conditions, there are several adaptation strategies that are already commonly practised in northern Ghana. Among these are modifying agricultural practices (including diversification or modification of the crops cultivated), diversifying livelihood strategies to include activities outside of the agricultural sector, and increasing migration to southern Ghana, especially to urban areas (Stanturf *et al.*, 2011; Laube *et al.*, 2008; Gyasi *et al.*, 2006). To minimize the risk of crop failure, early maturing crops such as soybean, onion, and sweet potato have replaced traditional crops that take longer to mature such as the traditional sorghum, groundnuts, and millet (Badmos *et al.*, 2014; Gyasi *et al.*, 2006). Cultivation of early maturing maize varieties has been increasingly employed as an adaptation strategy in the Upper East Region of Ghana (Abarike *et al.*, 2014).

Access to credit and fertiliser subsidies is considered to be key for enhancing farm household resilience to the impacts of climate change (Di-Falco *et al.*, 2011; Bryan *et al.*, 2009). The use of fertiliser (in terms of kilograms of nutrients applied per hectare) is lowest in Africa relative to other parts of the world (Morris *et al.*, 2007), and improving access to fertiliser subsidies is considered an effective way of increasing fertiliser usage (Yawson *et al.*, 2010). Furthermore, credit for the purchase of agricultural inputs helps ensure the availability of seeds, pesticides and fertiliser (Ebanyat *et al.*, 2010). There are various programmes in Ghana that support farmers in their efforts to improve agricultural production. Two examples are the Block Farm Programme (BFP) and the Northern Rural Growth Programme (NRGP) (IFAD, 2014; Angelucci, 2012). The BFP was established in accordance with the mandate of the Ministry of Food and Agriculture (MoFA) to accelerate the modernization of agriculture and increase agricultural productivity. In 2009, the programme was piloted in six regions of the country (Ashanti, Brong-Ahafo, Central, Northern, Upper East, and Upper West). The programme targets large areas of arable land (in blocks) at different locations and the production of selected commodities that are suitable for the specific agro-climatic conditions of each location. The BFP beneficiaries are provided with services such as fertiliser subsidies and the use of machines to improve their production, and repay credit provided in kind at harvest time (Angelucci, 2012). In 2009, the NRGP was implemented to contribute to agricultural and rural development, as well as the reduction of poverty in northern Ghana. The objective of the programme was to improve local income and the sustainability of agricultural and other rural livelihoods. The donors to this programme were the African Developmental Fund, the International Fund for Agricultural Development, and the National Government of Ghana (see www.afdb.org for greater detail). Under the NRGP, financial institutions were strengthened to improve access to farm credit for smallholder farmers (IFAD, 2014). Both the BFP and NRGP also promoted the cultivation of maize as an alternative to traditional crops.

Although maize has been cultivated in the study area for many years, traditional cereals such as millet and guinea corn are still most preferred among local farmers (Badmos, 2015). Due to erratic rainfall conditions, an improved variety of maize that matures early was identified as an important agricultural land-use adaptation option and a suitable substitute for the main traditional crops. According to Dah-gbeto (2014), the promoted maize variety can be harvested after 75 days as compared to 120 days for traditional maize varieties, but it requires more inputs. In this study, we explored the potential impact of providing credit for maize cultivation on heterogeneous households that exhibited a variety of agricultural land-use strategies and preferences with respect to their ability to cope with the effects of climate change.

Incorporating decision-making among heterogeneous households requires an agent-based or multiple-agent simulation model (hereafter MAS). According to Patt & Siebenhuner (2005), MAS models provide a suitable tool for improving the understanding of related problems, such as situations in which: (i) individual reactions to a problem impact choices made by others, (ii) new technologies emerge offering solutions to the problem, and (iii) social dilemmas affect individual responses. In recent years, MAS models have been applied to explicitly simulate the implications of decision-making processes (Villamor *et al.*, 2011; Parker *et al.*, 2003; Matthews *et al.*, 2007) by extending process-based modelling to the socio-economic components of decision-making (Villamor *et al.*, 2012a; An, 2012; Barthel *et al.*, 2008). This is because humans often make decisions in response to changes in their environment that in turn will change the context for future decisions (Villamor *et al.*, 2012b). The MAS models have been valuable for improving our understanding of climate change adaptation (Troost & Berger, 2014; Wang *et al.*, 2013; Balbi & Giupponi, 2010), as well as land-use change and the interactions between social and ecological systems (Morgan & Daigneault, 2015; Villamor *et al.*, 2014; Iwamura *et al.*, 2014; Belem *et al.*, 2011; Le *et al.*, 2010). In Africa, environmental science applications of MAS models have shown improvements in recent years (Badmos *et al.*, 2015a; Belem & Muller, 2013; Saqalli *et al.*, 2011; Bharwani *et al.*, 2005).

The Land Use Dynamic Simulator (LUDAS) is a MAS platform that has been applied to a wide range of contexts, such as: (i) land-use change in humid areas of Vietnam (VN-LUDAS) (Le, 2005; Le *et al.*, 2008); (ii) ecosystem service trade-offs in rubber agro-forest landscapes of Indonesia (LB-LUDAS) (Villamor, 2012; Villamor *et al.*, 2014); and (iii) vulnerability of coastal zones of Sri Lanka SRL-LUDAS) (Kaplan, 2011). In Ghana, adapted LUDAS models (GH-LUDAS and SKY LUDAS) have been applied to investigate land-use change in the Atankwidi watershed of northern Ghana (Schindler, 2009; Amadou, 2015). The Vea-LUDAS model is designed to assess the impacts of adaptation strategies on agricultural land-use in semi-arid areas of Ghana.

Access to credit has been identified by local residents in the study area as an appropriate agricultural land-use adaptation strategy for coping with the effects of climate change (Badmos *et al.*, 2015b). Hence, this study assesses the potential impact of providing credit for maize cultivation on household crop production.

Study area

This study was conducted in the Vea watershed (Figure 1) in the Upper East Region (UER) of Ghana. The watershed is one of the pilot areas involved in the West Africa Science Service Centre on Climate Change and Adapted Land Use (WASCAL) programme, located between latitudes 10^0 43′ 44″ to 11^0 0′ 49″ north and longitudes 10 0′ 3″ to 00 45′ 17″ west. The Vea watershed is a sub-watershed of the White Volta, occupying parts of both Burkina Faso and Ghana, with a total area of about 8 km^2 and 293 km^2 respectively. The Ghanaian section of the watershed corresponds to the Bongo and Bolgatanga districts of the UER. Most of the UER is West African semi-arid Guinea Savannah (Adu, 1972). The UER covers 8842 km^2, which represents 3.7 per cent of the total area of Ghana (GSS, 2012). The UER currently has an estimated population of 1 046 545 (48.4 per cent male and 51.6 per cent female), which represents 4.2 per cent of the country’s population, exhibiting an annual growth rate of 1.2 per cent between 2000 and 2010. The region has an average household size of 5.8; it is mostly rural

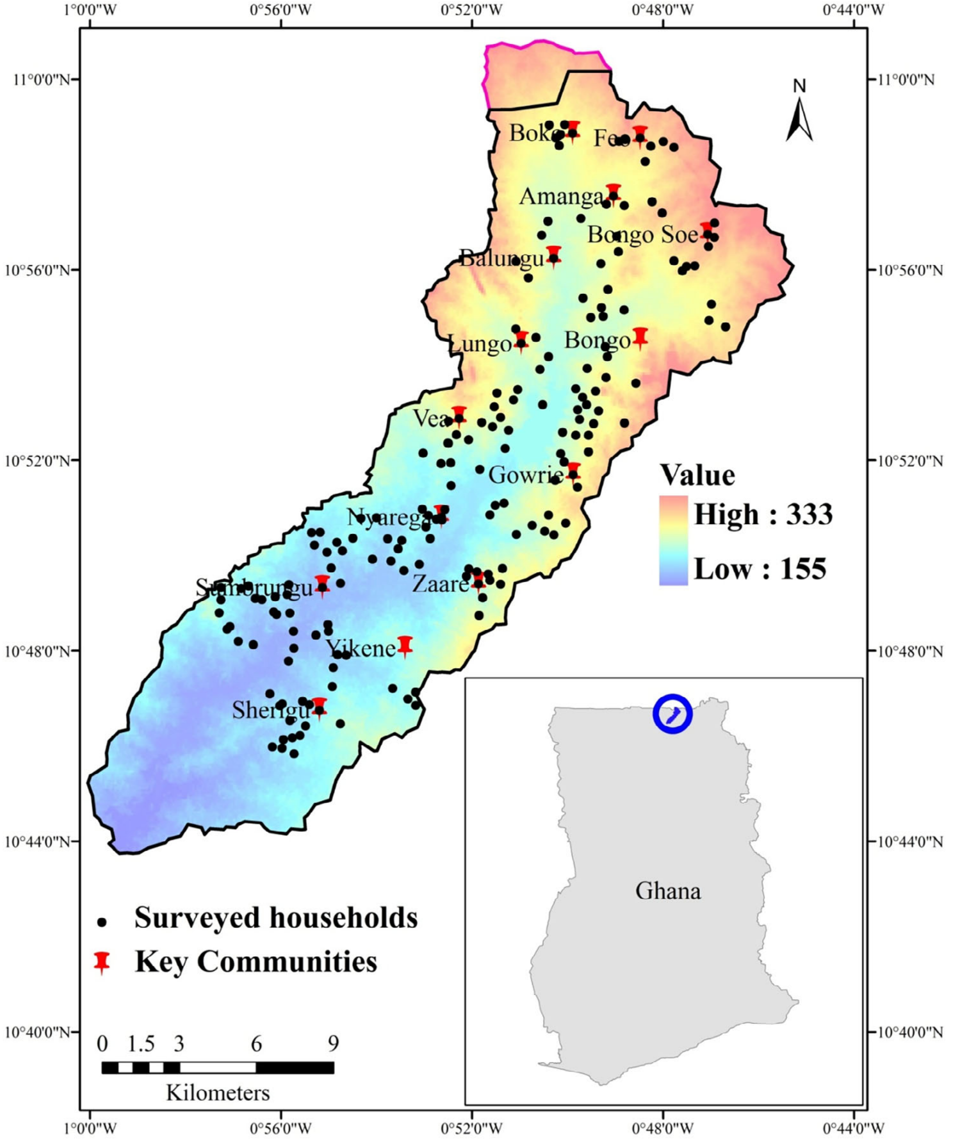

Figure 1. *Location of study area. The upper pink boundary represents the Burkina Faso section of the watershed.*
Source: **Digital Elevation Model obtained from the United States Geological Survey.**

(79 per cent), and has a population density of 118.4 individuals per kilometre, which exceeds the country's mean population density of 79 individuals per kilometre (GSS, 2012).

The rainfall and temperature pattern in the study area is presented in Figure 2. The annual rainfall pattern in the region is mono-modal, with a rainy season peak occurring between July and September. Annual precipitation over the past four decades averaged at 1044 mm, which is typically sufficient for a single wet season crop (IFAD, 2007). The rainy season in the UER is not only relatively short, but also erratic

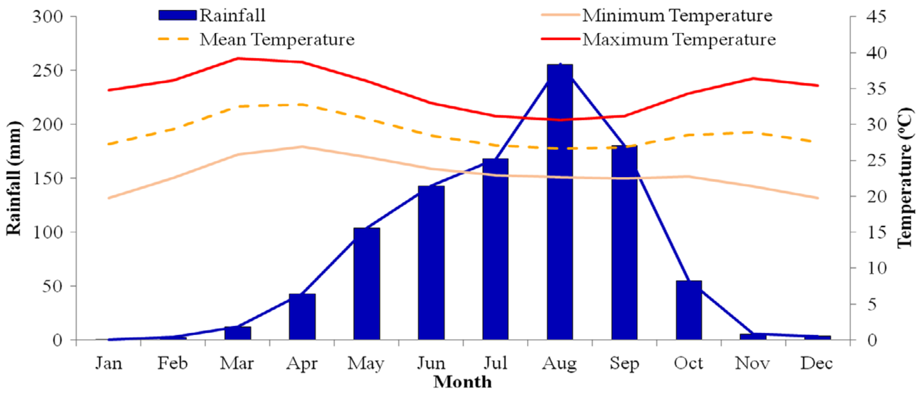

Figure 2. ***Average rainfall, minimum and maximum temperature between 1985-2010 in Bolgatanga, Upper East Region of Ghana.***
***Source*: Ghana Meteorological Agency.**

with respect to the onset, duration and intensity of rainfall, creating considerable inter-annual variability in agricultural production (IFAD, 2007). The mean annual temperature is approximately 29° C, while the absolute minimum ranges from 15° to 18° C (Mdemu, 2008).

Agricultural activities are the main source of income for most inhabitants of the region (Liebe, 2002; Barry *et al.*, 2005). About 70 per cent of the economically active population (15+ years old) is involved in agriculture, followed by service and retail, and then crafts and trades, which account for 10 per cent each of the population (GSS, 2012). There is limited irrigated crop production during the dry season. Millet (*Pennisetum* spp.) and Guinea corn (*Sorghum* spp.) are the most important grain staples grown in the UER and Upper West Region of Ghana, while maize (*Zea mays*), millet, and sorghum are the most important staples in the Northern Region (Dietz *et al.*, 2004). There are two common millet cultivars in the study area—(i) a short-season variety or early millet (*naara*) that can be harvested in July and (ii) a long-season variety or late millet (*zia*) that is harvested in November or December. Early millet is typically inter-cropped with either late millet or Guinea corn (*kimulga*) in fields closest to households where soil fertility is often highest (Blench, 2006).

The region has already experienced climate change impacts such as shifts in the temporal patterns of the rainy season and increased irregularities in overall climatic conditions. The most significant problem for farmers in northern Ghana is the erratic nature of rainfall in terms of both total amount and spatial distribution and this has made agricultural planning very difficult (van der Geest & Dietz, 2004). In the study area, rainfall is a key determinant of agricultural land-use options. Dietz *et al.* (2004) found that the rainy season in the UER was becoming shorter and more unpredictable with respect to overall precipitation and temporal distribution. Traditional land preparation practices have changed due to reduced duration of planting seasons (Laube *et al.*, 2008).

Methods

Data collection and analysis

The primary data collection techniques in this study were household surveys and physical measurements of field characteristics. A total of 186 households were randomly selected to participate in the survey effort (conducted between January and July 2013), which was designed to describe household and land-use characteristics. The survey also explored the willingness of households to adopt the specific policy intervention under consideration (credit for maize production). The coordinates of each household and agricultural plot location were obtained with a Global Positioning System (GPS) device, which allowed us to measure their respective areas. Based on the results of principal component analyses (Table 1) and cluster analyses (Table 2), two types of households were identified (Badmos *et al.*, 2015b). Type-1 households (n = 111) were better-off than Type-2 households (n = 75) both in terms of land area cultivated and income generated from rainfed rice. On the other hand, Type-2 households were better off than Type-1 households in terms of area cultivated for maize and income generated from maize. Further, Type-2 households were better-off than Type-1 households in terms of labour potential (human asset), total land area cultivated per capita (natural asset) and total income generated per capita (financial asset). These household types were used for model parameterization such that simulated households were most likely to adapt the behaviour of the most proximal household type.

Relevant spatial data (land cover distributions, topographic characteristics, soil features, etc.,) were pre-processed and modified using geographic information system software (ArCGIS Version 9.3). Based on the household survey and spatial characteristics data, the major determinants of crop choices (agricultural land-use of each household type) were generated using multinomial logistic regression (Equation 1), which provided the basis for current farming decisions (Badmos, 2015).

$$\boldsymbol{Pij} = \frac{e^{\sum_{j=1}^{k} a \;+\; b_{kj} X_{kji}}}{\sum_{j=1}^{j} e^{\sum_{j=1}^{k} a \;+\; b_{kj} X_{kji}}} \tag{1}$$

where, i = cases, j = categories and k = independent variables.

MAS model

The overall purpose of the Vea-LUDAS model is to assess the impact of adaptation strategies in Vea catchment, Upper East Region of Ghana. The purpose of this paper is to present the impact of one such strategy i.e. maize cultivation credit on crop production. The basic overview, design concept and details, plus decision making (ODD+D) protocol of the model can be found as supporting information in Appendix S1 (Badmos *et al.*, 2015a). The ODD is a standard procedure for describing individual and agent based models (Grimm *et al.*, 2006; Grimm *et al.*, 2010). The ODD+D expands and refines the ODD protocol to establish a standard for describing ABMs that include human decision-making (Muller *et al.*, 2013). The main simulation steps for Vea-LUDAS are presented in Figure 3.

Crop yield estimation sub-model

This sub-model follows the Cobb-Douglas production function—Equation 1 (Cobb & Douglas, 1928). The yield (P_{Yield}) of the various agricultural land use classes (Table 3) were explained by predictors such as seed input (P_{Seed}), labour input (P_{Labour}), fertiliser input ($P_{Fertili}$), upslope area, ($P_{Upslope}$), and wetness index values ($P_{Wetness}$). Because water is an important factor for crop production, especially in semi-arid areas, we used a wetness index to describe watershed soil moisture conditions quantitatively.

Table 1. Total variance explained by extracted components using Principal Component Analysis.

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Components	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.805	20.889	20.889	4.805	20.889	20.889	2.977	12.944	12.944
2	2.861	12.44	33.329	2.861	12.44	33.329	2.64	11.478	24.422
3	2.681	11.658	44.988	2.681	11.658	44.988	2.411	10.485	34.907
4	1.717	7.465	52.453	1.717	7.465	52.453	2.214	9.625	44.532
5	1.484	6.454	58.906	1.484	6.454	58.906	2.117	9.204	53.736
6	1.45	6.306	65.212	1.45	6.306	65.212	1.848	8.035	61.771
7	1.183	5.144	70.356	1.183	5.144	70.356	1.787	7.772	69.543
8	1.021	4.439	74.796	1.021	4.439	74.796	1.208	5.253	74.796
9	0.82	3.564	78.359						

Table 2. Descriptive statistics of key categorizing variables for each household type.

Variable	Household	Mean	Std. Err. of Mean	Std. Deviation
Labour potential	1	6.6	0.3	2.7
	2	9.3	0.4	3.4
Land area cultivated for rainfed rice (m^2)	1	840.9	95.7	1008.2
	2	2345.6	344.6	2984.2
Income from rainfed rice (Cedis)	1	122.8	14.6	154.3
	2	357.7	54.0	468.0
Land area cultivated for irrigated rice (m^2)	1	63.6	21.9	231.1
	2	372.6	113.4	982.0
Income from irrigated rice (Cedis)	1	14.2	5.4	57.2
	2	61.2	18.8	163.2
Per-capita income (Cedis)	1	139.2	13.4	141.5
	2	185.1	17.2	149.3
Land area cultivated per capita (m^2)	1	1896.7	156.6	1649.6
	2	1935.3	146.8	1271.4
Income from traditional cereals (Cedis)	1	219.4	15.3	161.5
	2	449.9	41.1	355.8
Number of bullock ploughs	1	0.2	0.0	0.5
	2	0.7	0.1	0.7
Number of cattle	1	1.4	0.2	2.3
	2	4.8	0.5	4.3
Land area cultivated for maize (m^2)	1	408.8	148.2	1561.0
	2	808.3	206.1	1785.0
Income from Maize (Cedis)	1	14.1	4.5	47.0
	2	40.5	11.1	96.3
Dependency ratio	1	0.5	0.0	0.4
	2	1.1	0.1	0.7

Note: Household 1 = 111; Household 2 = 75.

According to Ma *et al.* (2010), wetness indices are the most commonly used indicators for static soil moisture content, which can be used to represent the moisture component of the landscape within the sub-model. Table 4 presents a summary of the crop yield estimation efforts.

$$P_{Yield} = A * P_{seed}^{b1} * P_{Labour}^{b2} * P_{Fertili}^{b3} * P_{Upslope}^{b4} * P_{Wetness}^{b5} \quad (2)$$

where P_{Yield} is the crop yield, A is a constant, P_{Seed} is the seed input, P_{Labour} is the labour input, $P_{Fertili}$ is the fertiliser input, $P_{Upslope}$ is the upslope area of the land, $P_{Wetness}$ is the wetness index of the land; and b1 to b5 represent yield elasticity for the corresponding parameters.

There are different sources of farm labour in the study area, such as family, communal and paid labour. Due to the difficulty of properly accounting for communal and paid labour in the model, we ignored the process of searching for land if there is extra labour, following Le *et al.* (2008).

Maize credit adoption sub-model

This sub-model follows the integrated FarmChoice module of LUDAS (Le *et al.*, 2008) and the PES adoption sub-model of Villamor *et al.* (2014). At each time step, this sub-model randomly determines the probability of whether or not a household agent accepts credit to cultivate maize based on preference coefficients generated using binary

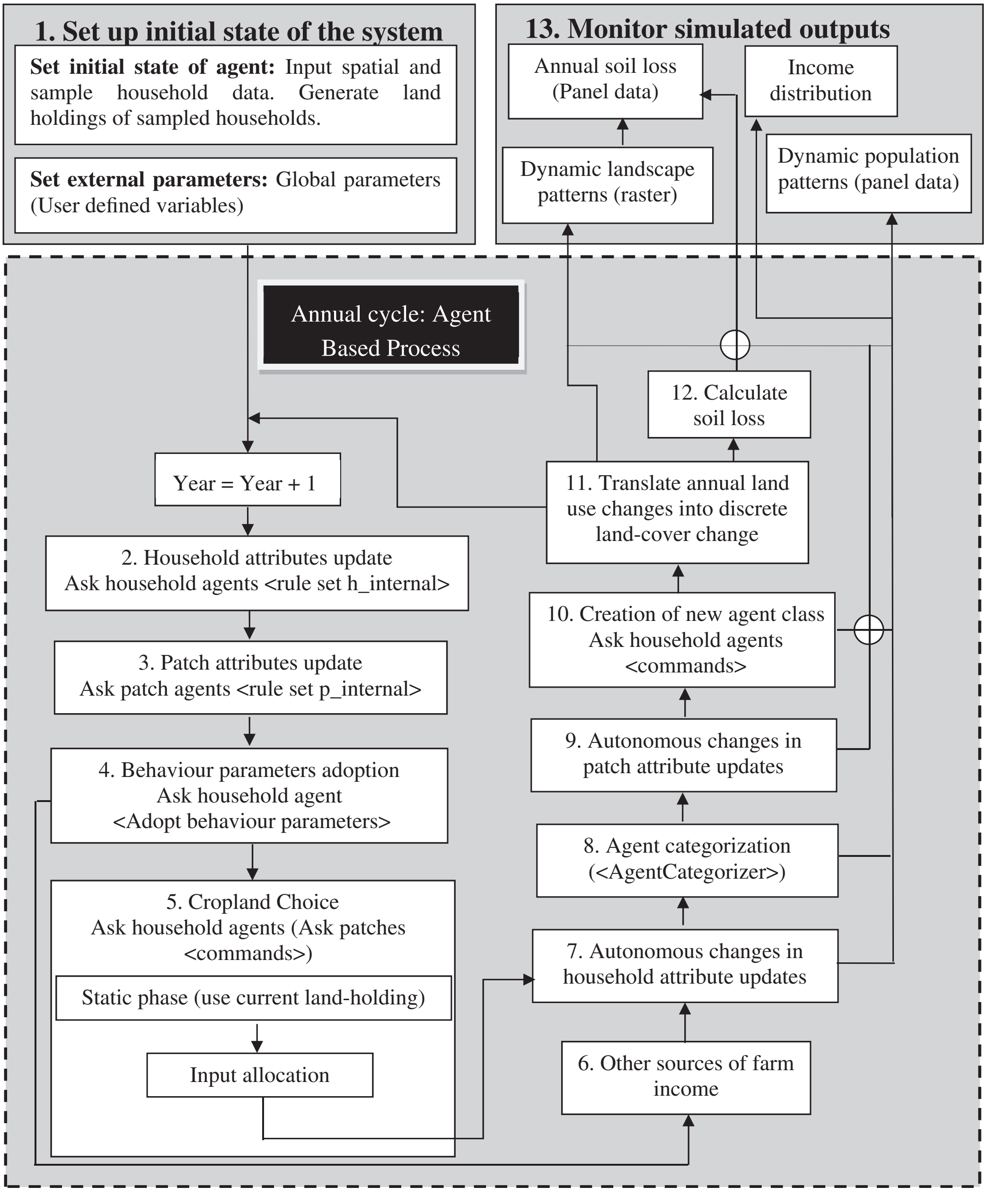

Figure 3. *Main simulation steps of the Vea-LUDAS model.*
Source: **Badmos *et al.*, 2015a.**

logistic regression (Equation 3), otherwise, the agent maintains their current land use (see Table 5 for model summary).

$$Log\,(Pi/1-Pi) = B_o + B_I X_I + B_2 X_2 + \ldots\ldots B_k X_k \qquad (3)$$

Table 3. Classification of agricultural land-use choices.

#	Sub-category / description	Code
1	Traditional cereals culture where Guinea corn (GC) is main crop	Guinea corn based
2	Traditional cereals culture where Late millet (LM) is main crop	Late millet based
3	Traditional cereals culture where there is equal ratio of GC and LM	Traditional cereals
4	Groundnut in mixture of other crops	Mixed groundnut
5	Groundnut in a mono culture	Mono groundnut
6	Rice is the main crop	Rice
7	Maize is the main crop	Maize

where, *Pi/1-Pi* = Probability value, i = i-th observation in the sample, *Pi* = Predicted probability of farmer choice, B_o = Intercept term; and B_I, B_2, B_k = coefficients associated with explanatory variables X_I, X_2, X_k.

Scenarios

We compared the following main scenarios:

i. The baseline or business-as-usual scenario (BS)—represents current land use, whereby farmers continue cultivating their customary crop without any explicit intervention.
ii. The maize credit scenario (MCS)—represents situations where household agents are offered credit for maize cultivation. The corresponding decision of whether or not to accept credit for maize cultivation depends on the results of the maize credit adoption sub-model.

An annual population growth rate of 1.2 per cent was specified in the model for both scenarios following GSS (2012).

Model validation

Le *et al.* (2010) argued that point-to-point history matching cannot be the only test to ascertain the validity of such a complex human-environmental systems model like the MAS model. Rather a series of tests will need to be executed to increase the user's confidence in the usefulness of the model. In the same vein, Villamor *et al.* (2012a) acknowledged that harmonizing the elements and processes of a model with structures and processes in the system being modelled is a better way of conceptually determining validity as opposed to testing for one-to-one accuracy.

In this study, the model output (crop yields) was matched with data from a legitimate authoritative source (MoFA). The time series yield data for the two districts (Bongo and Bolgatanga) of the study area were compared with projected yields. Furthermore, we also used stakeholder centred validation approaches such as the participatory scenario exploration exercise or PSEE (Badmos *et al.*, 2014) and a role-playing game exercise (Villamor & Badmos, 2016).

Results

Agricultural land-use change

The projected changes in areas cultivated with different crops from year 1 to year 20 under the two scenarios are presented in Figure 4. Changes in areas cultivated with

Table 4. Crop yield estimation summary.

Crop yield model summary	Non-standardized coefficient (ß)	Standard error of ß
Guinea corn based		
P = 0.000***; Ln(P_{Yield}) = 13.3170; Adjusted R^2 = 0.506		
Constant	7.028	1.501
Ln of seed input (p_Seed)	0.333**	0.138
Ln of labour input (p_Labour)	0.612***	0.147
Ln of contributing upslope area (p_Upslope)	–0.044	0.115
Ln of wetness index value (p_Wetness)	0.041	0.131
Late millet based		
P = 0.001***; Ln(P_{Yield}) = 13.1159; Adjusted R^2 = 0.566		
Constant	7.398	2.006
Ln of seed input (p_Seed)	0.390*	0.215
Ln of labour input (p_Labour)	0.495*	0.276
Ln of contributing upslope area (p_Upslope)	–0.076	0.115
Mixed traditional		
P = 0.073*; Ln(P_{Yield}) = 12.941; Adjusted R^2 = 0.25		
Constant	9.793	1.482
Ln of contributing upslope area (p_Upslope)	0.176**	0.076
Ln of seed input (p_Seed)	0.166	0.160
Ln of labour input (p_Labour)	0.022	0.186
Mixed groundnut		
P = 0.000***; Ln(P_{Yield}) = 13.6851; Adjusted R^2 = 0.605		
Constant	5.135	1.005
Ln of seed input (p_Seed)	0.580***	0.096
Ln of labour input (p_Labour)	0.353***	0.102
Ln of wetness index value (p_Wetness)	–0.020	0.079
Ln of contributing upslope area (p_Upslope)	–0.003	0.076
Ln of groundnut monoculture yield		
P = 0.053*; Ln(P_{Yield}) = 13.6681; Adjusted R^2 = 0.479		
Constant	4.074	3.934
Ln of seed input (p_Seed)	0.888*	0.457
Ln of labour input (p_Labour)	–0.066	0.469
Ln of contributing upslope area (p_Upslope)	0.933	0.567
Ln of wetness index value (p_Wetness)	–0.905	0.576
Ln of Rice yield		
P = 0.000***; Ln(P_{Yield}) = 14.0891; Adjusted R^2 = 0.522		
Constant	8.427	0.888
Ln of seed input (p_Seed)	0.393***	0.111
Ln of labour input (p_Labour)	0.274*	0.138
Ln of fertiliser input (p_Fertili)	0.028**	0.014
Ln of contributing upslope area (p_Upslope)	–0.082	0.068
Ln of wetness index value (p_Wetness)	0.026	0.064
Ln of maize yield		
P = 0.003***; Ln(P_{Yield}) = 13.4797; Adjusted R^2 = 0.566		
Constant	7.031	2.527
Ln of seed input (p_Seed)	0.339	0.269
Ln of labour input (p_Labour)	0.570*	0.266
Ln of fertiliser input (p_Fertili)	0.026	0.024
Ln of wetness index value (p_Wetness)	0.003	0.078

Note: *, ** and *** indicate statistical significance at the 90 per cent, 95 per cent and 99 per cent confidence levels respectively.

Table 5. Bi-Logit estimation of determinants of household choice to accept maize cultivation credit.

Variable code	Variable description	Coefficient	Std. Error
β	Intercept	–1.0779	(1.9195)
h_age	Age of household head	0.0117	(0.0147)
h_size	Total number of people in the household	–0.1956	(0.1812)
h_depend	Ratio of dependent to non-dependent household members	0.1546	(0.3706)
p_percap	Total land area cultivated by household per person	0.0010	(0.0007)
p_trad	Total land area cultivated for traditional cereal crops	0.0003	(0.0001)***
p_rainy	Total land area under rain-fed crops	–0.0002	(0.0001)*
p_plot	Number of plots cultivated	0.2056	(0.2122)
I_percapita	Total household income per person	–0.0134	(0.0056)**
I_rainy	Total income generated from rain-fed crops	0.0018	(0.0007)**
h_d_river	Household distance from river	–0.0005	(0.0003)

Note: Likelihood ratio test (chi-square statistics) = 18.489; df = 10; p = 0.047; R^2 = 0.245; ***, ** and * indicate statistical significance at 0.01, 0.05 and 0.1 respectively.

Guinea corn-based, late millet-based, mixed traditional cereal, mixed groundnut, and groundnut monoculture production systems were significantly higher ($p < 0.05$) under the BS compared to MCS. There was no significant difference in the areas under rice cultivation, but the area under maize cultivation was significantly higher ($p < 0.05$) under MCS compared to BS. Under the BS scenario, the change in areas for each agricultural land-use was associated with the annual increase in household numbers, reflecting the fact that there was no land use change among households. Under the MCS, changes in areas for each agricultural land-use were associated with annual increases in household numbers and the change in maize adoption rates (Figure 5) as influenced by credit for maize cultivation.

Household crop yields and income

The projected mean annual crop yields for rice (1.58 t/ha) and maize (1.14 t/ha) under the BS were compared with the annual crop yields reported by MoFA for the Bongo and Bolgatanga districts and were found to be within the reported confidence intervals ($p < 0.05$) for those districts. We assigned equal weights to all crops to aggregate the yields. The projected annual aggregated crop yield was higher under the MCS compared to BS (Figure 6). Similarly, projected mean annual aggregated crop yields were significantly higher ($p < 0.05$) under the MCS compared to BS. The mean annual farm household income was higher under the MCS than BS (Figure 7), but was not statistically different at $p < 0.05$.

Evaluating model behaviours using a validation approach

Members of the sample households participated in participatory and gaming exercises. Due to the short production period, participants expressed their preferences for maize production during the role-playing game exercise. Moreover, surveyed farmers were also questioned about their views on the government maize subsidies (Badmos *et al.*, 2014; Villamor & Badmos, 2016). In this way, we were able to validate the decision making sub-model. During the PSEE some farmers chose to decline credit for maize cultivation because they were already cultivating maize and

Figure 4. *Percentage of area covered by different agricultural landuse between year 1 and year 20 under the baseline and maize credit scenarios.*
Source: Author's computation.

did not have land available for expansion (Badmos *et al.*, 2014). Farmers also stressed the importance of traditional crops. The model predicted that maize adoption rates would become stable over time because farmers would continue to plant traditional crops.

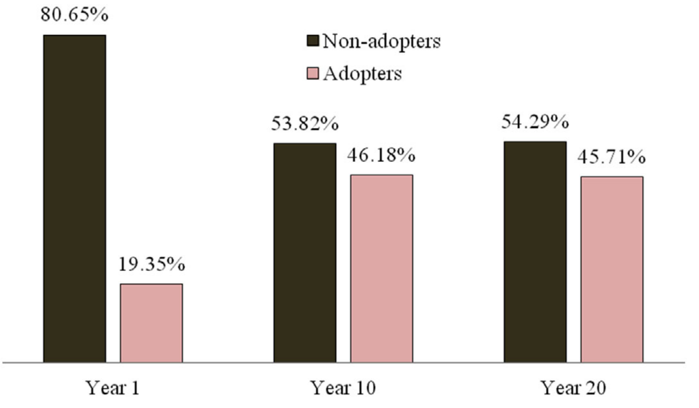

Figure 5. ***Percentage change in maize adopters between year 1 and year 20.***
***Source*: Author's computation.**

Discussion

Access to credit for maize cultivation (the maize credit scenario) significantly ($p < 0.05$) influenced the pattern of agricultural land-use change predicted for the study area through replacement of production systems featuring Guinea corn, late millet, mixed traditional cereals, and both mixed and monoculture groundnut with maize production. This implies that farmer access to credit for maize cultivation significantly ($p < 0.05$) increased maize production area at the expense of traditional crops. Access to credit was similarly found to have stimulated cotton expansion in Burkina Faso and Mali (Brons *et al.*, 2004), mainly into new areas with high quality soils (Reardon & Barrett, 2001). In some parts of south western Ethiopia, access to credit was found to have a limited influence on the conversion of forest to agriculture at the expense of the provision of ecosystem services (Girma & Hassan, 2014). Although our findings only identified expansion of the area of maize cultivated at the expense of traditional crops, this could be related to the fact that land availability was rated as an important adaptation constraint in the study area (Badmos *et al.*, 2015b). Suitable plots of land for

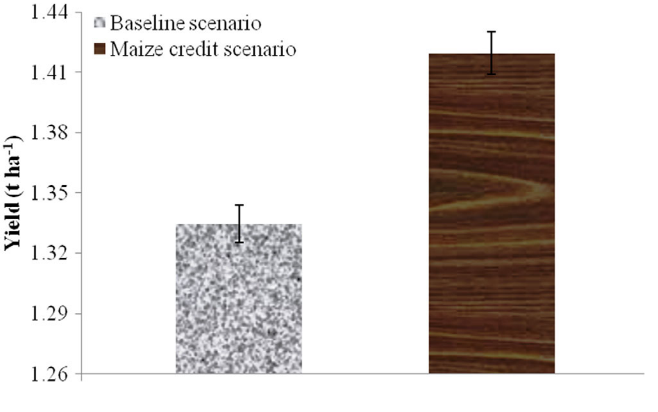

Figure 6. ***Projected aggregated mean annual crop yields.***
***Source:* Author's computation.**

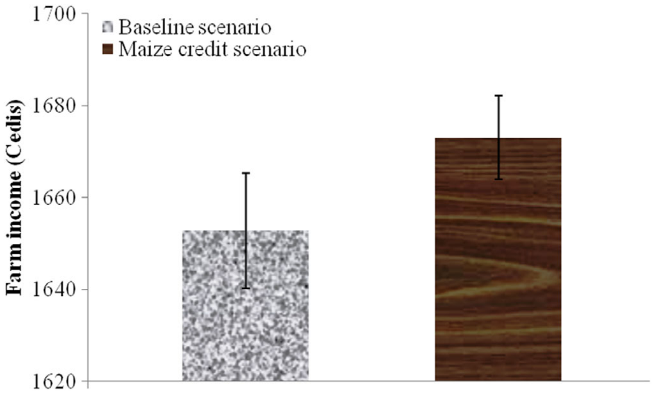

Figure 7. *Projected mean annual farm household income.*
Source: **Author's computation.**

crop production in the study area are usually found far from the farmer households that were surveyed.

Land-use change can impact ecosystem functions at the landscape level (Van Noordwijk *et al.*, 1997; Lal, 2004). In our study, however, the feedback effects over the long term (i.e. soil degradation) were not captured due to the lack of available data for parameterizing key ecosystem functions such as soil fertility. Nonetheless, soil loss associated with land-use change was considered in a companion study (Badmos *et al.*, 2015a).

Among rural subsistence farming communities, aggregated household crop yields were projected to increase with greater maize adoption. This is because the improved maize variety produces higher yields than traditional crop production systems such as Guinea corn-based, late millet-based, mixed traditional cereal, and mixed groundnut production systems. A similar trend has been observed in Senegal, in which financial support for adaptation through facilitating access to credit and agricultural practice innovations have resulted in yield increases (Savane, 2013). Greater access to credit for farm inputs had also resulted into higher crop yields in Mali (Ebanyat *et al.*, 2010). This implies that food production, as an aspect of food security, can be improved through increasing access to credit. Although this seems like a promising policy option, especially in this region, how to sustain it is an important question. Issues such as negative externalities (from intensive use of fertilisers), risk of losses from crop failure due to climate variability, and insecure land tenure are realities that should be taken into account in the evaluation of potential policy measures (Sumberg, 2012). Farmers in the study area maintained a strong preference for traditional crops (Badmos *et al.*, 2014), thus increasing overall household yields with a particular crop may not completely satisfy nutritional needs (i.e. food quality). Hence, to avoid cases of maladaptation, which may arise due to cultivation of single crops, other interventions should be put in place to complement the credit provision, thereby making the community resilient to climate change impact. These may include improved fertiliser subsidy schemes, improved irrigation infrastructure, improved land preparation equipment, greater accessibility of improved crop varieties, etc.

We estimated household farm income from predicted household crop yields, and it was not surprising that household farm income was projected to increase as the area for maize cultivation increases. As shown in Table 2, total income per capita is associated with household adoption of maize credit, which suggests that households with lower income are more likely to adopt maize cultivation. However, the adoption of maize due to access to credit did not significantly influence the predicted total farm household income because the market value of maize is lower than that of traditional crops.

The MAS approach allowed us to combine data collecting techniques such as household surveys, interviews and participatory exercises to capture the complexities of decision making among local farmers and to improve the decision rules of the model to reflect reality as accurately as possible. The following limitations, however, should be addressed in similar future research efforts. Data availability remains a serious challenge, particularly in this region (and Sub-Saharan Africa as a whole). For example, although soybean cultivation was identified as another agricultural land-use change adaptation strategy in the study area, there were insufficient available data for proper parameterization. Also, we identified three main labour categories (family, communal and paid), however, desegregating these labour categories further would require other programming approaches. Due to time limitations, this version of Vea-LUDAS focused only on family labour availability. Water is a very critical variable with respect to agricultural production and productivity in this region, and farmers in the study area demonstrated sensitivity to rainfall in terms of their agricultural land-use options (Badmos *et al.*, 2014). Although, we used topographic water indicators such as contributing upslope area and wetness index values to estimate crop yields, time-series precipitation data were lacking. As such, it is recommendable to (i) consider such data in future research efforts and (ii) forge such data with a better understanding of how climate change affects ecological, social, political and economic systems locally. In this way, a more holistic scenario could be constructed to better capture reality at the local level.

Conclusions and recommendations

Lack of access to credit is an important constraint on the ability of farmers to adapt to the impacts of climate change. Merely acknowledging the response of heterogeneous households to farm credit is insufficient—it is also necessary to understand the impacts of that response in order to assess the impact of increased credit availability. Our application of the Vea-LUDAS model to semi-arid Ghana did offer insight into the potential impact of an existing agricultural land-use change adaptation strategy (farm credit) on land-use change and farm household livelihoods. The application of the Vea-LUDAS model to explore the response of human agents and landscapes to credit is a novel approach. Our findings indicate that credit for maize cultivation (modelled in the maize credit scenario) significantly increased conversion of traditional crop production areas to maize production areas, and this also increased aggregated crop yields relative to the business as usual scenario. Landuse conversions must, however, be approached with adequate caution to prevent increasing risks associated with the impacts of climate change. For example, shifting to monoculture crop systems could incur greater risks because unanticipated setbacks could result in total crop failure. Instead, an all-encompassing policy strategy should strive to boost both crop production and household resilience to the effects of climate change at the same time. Furthermore, other interventions should be considered, such as improved fertiliser subsidy schemes, improved irrigation infrastructure, improved land preparation equipment, and greater accessibility to improved crop varieties, amongst others. Nevertheless, it remains unclear as to whether or not such interventions can sustainably contribute to overall food security in the long term.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1: ODD+D Protocol for Vea-LUDAS